Report from NA49

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The most recent data of NA49 on hadron production in nuclear collisions at CERN SPS energies are presented. Anomalies in the energy dependence of pion and kaon production in central Pb+Pb collisions are observed. They suggest that the onset of deconfinement is located at about 30 AGeV. Large multiplicity and transverse momentum fluctuations are measured for collisions of intermediate mass systems at 158 AGeV. The need for a new experimental programme at the CERN SPS is underlined.

[*]invited talk presented at Quark Matter 2004

1. Introduction

Since the first Pb-run at the CERN SPS (at 158 AGeV) in 1994 the NA49 experiment [1] collected a large set of data on hadron production in nuclear collisions. The data taking period ended in 2002 with Pb-runs at 20 and 30 AGeV. Several research programmes were undertaken by the NA49 Collaboration. Selected results of two of them, the energy scan programme and the system size dependence programme, are reported here. Other recent results of NA49 on the energy dependence of particle ratio fluctuations [2], (multi)strange hyperon production [3] and two pion correlations [4] were also presented during this conference. Finally our evidence for pentaquark candidates in p+p interactions at 158 AGeV was discussed [5].

The energy scan programme was motivated by the hypothesis [6] that the onset of the deconfinement phase transition is located between the top SPS and AGS energies. Within this project data on hadron production in central Pb+Pb collisions at 20, 30, 40, 80 and 158 AGeV were recorded. In this report we show the first results obtained at 20 AGeV which extend the previously measured hadron systematics [7,8] to the full SPS energy range from 20 to 158 AGeV.

The aim of the system size dependence programme is to study how the properties of strongly interacting matter change with its volume. Data on p+p, C+C, Si+Si and minimum bias Pb+Pb collisions at 158 AGeV and 40 AGeV were collected. Here we show new results on system size dependence of electric charge correlations and multiplicity fluctuations at 158 AGeV.

2. Energy dependence of hadron production in central Pb+Pb collisions

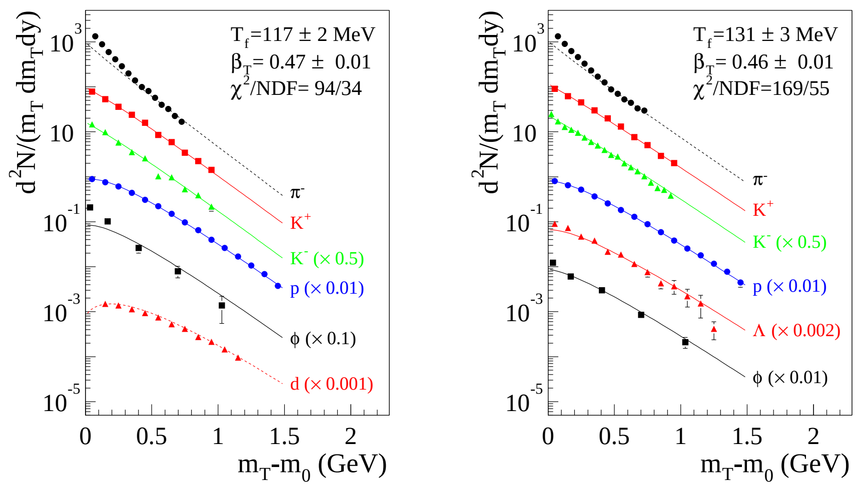

FIG. 1. Transverse mass spectra of hadrons produced in central Pb+Pb collisions at 20 (left) and 30 (right) AGeV. The solid lines indicate fits of a blast wave parametrization [9].

The transverse mass, m_T, spectra of hadrons measured in central (7.2%) Pb+Pb collisions at 20 and 30 AGeV are presented in Fig. 1. The data follow approximately the pattern expected within hydrodynamical approaches. As an illustration the fits of the blast wave parametrization [9] are shown. The thermal freeze-out temperature and the collective transverse velocity resulting from the fits are about 120 MeV and 0.5c, respectively. Similar values of these parameters were obtained at the higher SPS energies.

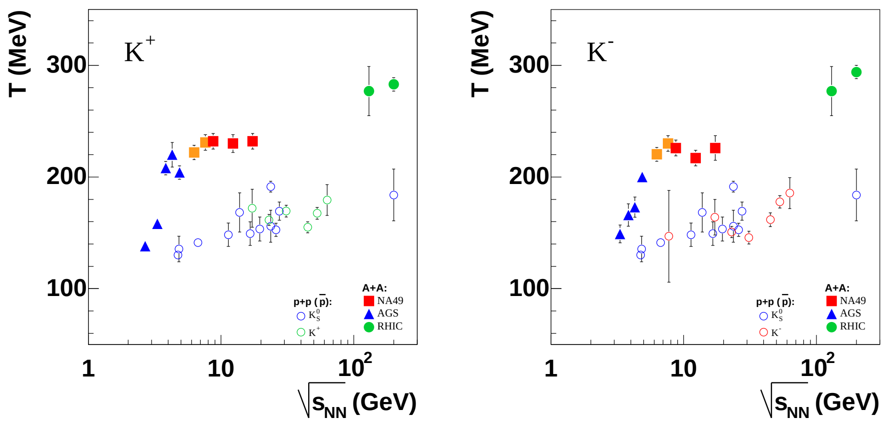

FIG. 2. Energy dependence of the inverse slope parameter, T, of the transverse mass spectra of K^+ (left) and K^- (right) produced in central Pb+Pb (Au+Au) collisions (solid symbols) and p+p interactions (open symbols). $\sqrt{s_{NN}}$ is the c.m.s. energy per nucleon-nucleon pair.

The shape of the m_T-spectra of kaons appears to be in a good approximation exponential, $1/m_T dn/dm_T \sim exp(-m_T/T)$, in the full studied energy range. Thus the shape of the spectra is well represented by their inverse slope parameter T. Its dependence on the collision energy is shown in Fig. 2 for central Pb+Pb (Au+Au) collisions [10] and p+p($\overline{\text{p}}$) interactions [11]. For heavy ion collisions a steep rise at AGS energies is followed by a plateau at SPS energies. At RHIC higher values are observed. The beginning of the plateau in this **step**-like dependence [10] is located at about 30 AGeV.

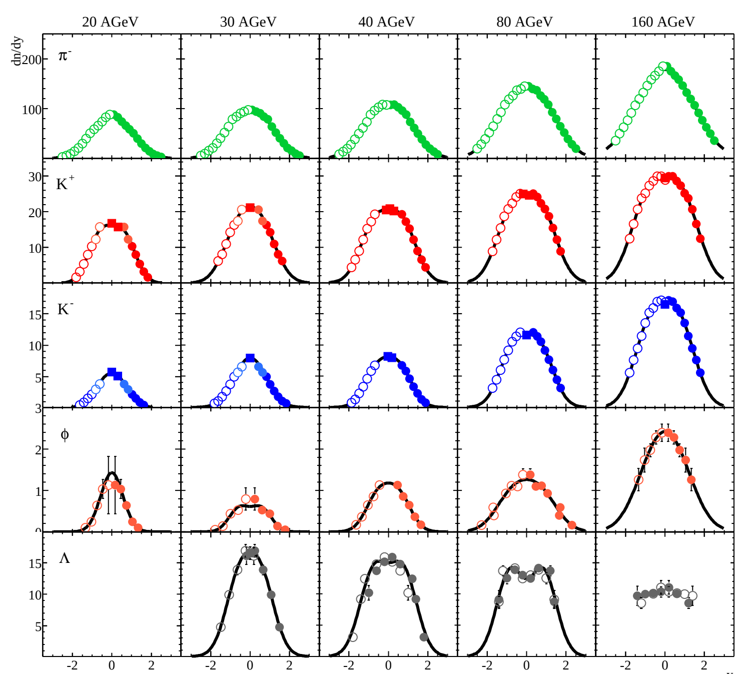

FIG. 3. The rapidity spectra of hadrons produced in central (7% at 20-80 AGeV, 5% (π^-, K^+, K^-) and 10% (ϕ, Λ) at 158 AGeV) at SPS energies. The closed symbols indicate measured points, open points are reflected with respect to midrapidity. The solid lines indicate parameterizations of the data used for the extrapolation of the yield to full phase space.

Rapidity y (y is the rapidity of a particle in the collision center-of-mass system) distributions of selected hadrons measured in central Pb+Pb collisions at 20-158 AGeV are plotted in Fig. 3. The large acceptance of the NA49 spectrometer and high resolution in particle identification [1] allow for reliable measurements of total mean multiplicities (denoted as $\langle ... \rangle$) of various hadronic species.

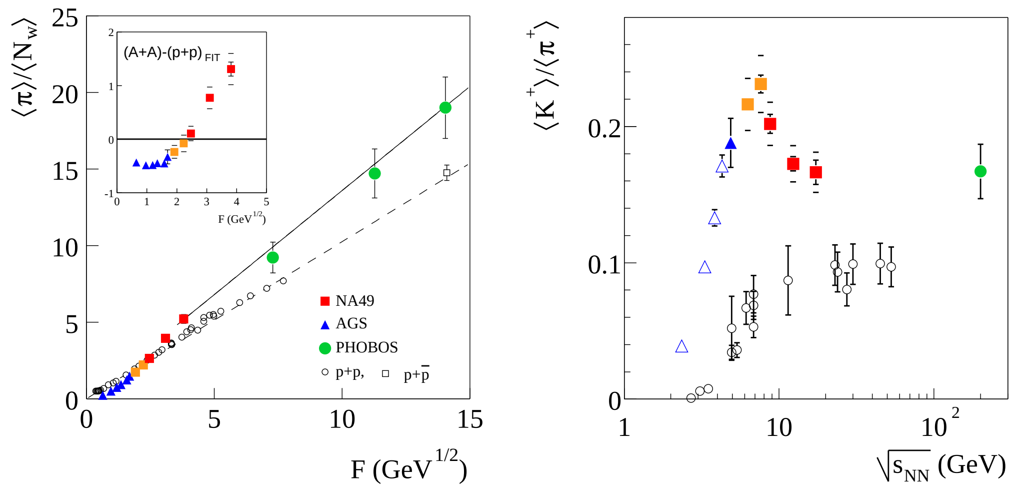

FIG. 4. Left: The dependence of total pion multiplicity per wounded nucleon on Fermi's energy measure F ($F \equiv (\sqrt{s_{NN}} - 2m_N)^{3/4}/\sqrt{s_{NN}}^{1/4}$, where $\sqrt{s_{NN}}$ is the c.m.s. energy per nucleon–nucleon pair and m_N the rest mass of the nucleon) for central Pb+Pb (Au+Au) collisions (closed symbols) and inelastic p+p($\overline{\mathrm{p}}$) interactions (open symbols). Right: The dependence of the $\langle K^+\rangle/\langle\pi^+\rangle$ ratio on the collision energy for central Pb+Pb (Au+Au) collisions (closed symbols) and inelastic p+p interactions (open symbols).

The dependence of mean multiplicity of pions ($\langle\pi\rangle = 1.5\cdot(\langle\pi^-\rangle + \langle\pi^+\rangle)$ per mean number of wounded nucleons, $\langle N_W\rangle$, on collision energy is shown in Fig. 4 (left) for central Pb+Pb(Au+Au) collisions and p+p($\overline{\mathrm{p}}$) interactions. A **kink**-like change from pion suppression to pion enhancement in central Pb+Pb (Au+Au) collisions is observed at about 30 AGeV in contrast to a linear increase seen for p+p($\overline{\mathrm{p}}$) interactions in the full energy range.

The $\langle K^+\rangle/\langle\pi^+\rangle$ ratio is plotted as a function of collision energy in Fig. 4 (right). A **horn**-like structure is observed for central Pb+Pb (Au+Au) collisions. The maximum of the horn is located at about 30 AGeV.

The anomalies observed in the energy dependence of hadron production (the **horn**, the **kink** and the **step**) at the low SPS energies are consistent with the predictions for the onset of the deconfinement phase transition [6]. These anomalies can not be reproduced with current string-hadronic (see e.g. Ref. [12]) and hadron gas models (see e.g. Ref. [13]).

2. System size dependence of hadron production at 158 AGeV

The correlations between positively and negatively charged hadrons were studied in p+p, C+C, Si+Si and Pb+Pb collisions at 158 AGeV [19] in terms of the balance function [14]:

$$B(\Delta\eta) = 0.5((N_{+-}(\Delta\eta) + N_{--}(\Delta\eta))/N_- + (N_{-+}(\Delta\eta) + N_{++}(\Delta\eta))/N_+), \qquad (1)$$

where $N_{ab}(\Delta\eta)$ is the number of pairs of particles of charges a and b separated by a pseudo-rapidity interval $\Delta\eta$ and N_-, N_+ are total numbers of negatively and positively charged particles used in the analysis, respectively. Hadrons within the acceptance limits, $0.005 < p_T < 1.5$ GeV/c and $2.6 < \eta < 5.0$ (p_T and η are transverse momentum and pseudo-rapidity in the laboratory system, respectively), which passed in addition the NA49 acceptance filter were used for the analysis. About 30% of all produced charged hadrons are accepted. As an example, the balance functions for central and peripheral Pb+Pb collisions and p+p interactions are shown in Fig. 5 (left). The distribution measured for central Pb+Pb collisions is significantly narrower than the spectra obtained for the string-hadronic model Hijing [15] and "shuffled" [16] events. "Shuffled" events are constructed from the real events by random redistribution of particle pseudo-rapidities within one event.

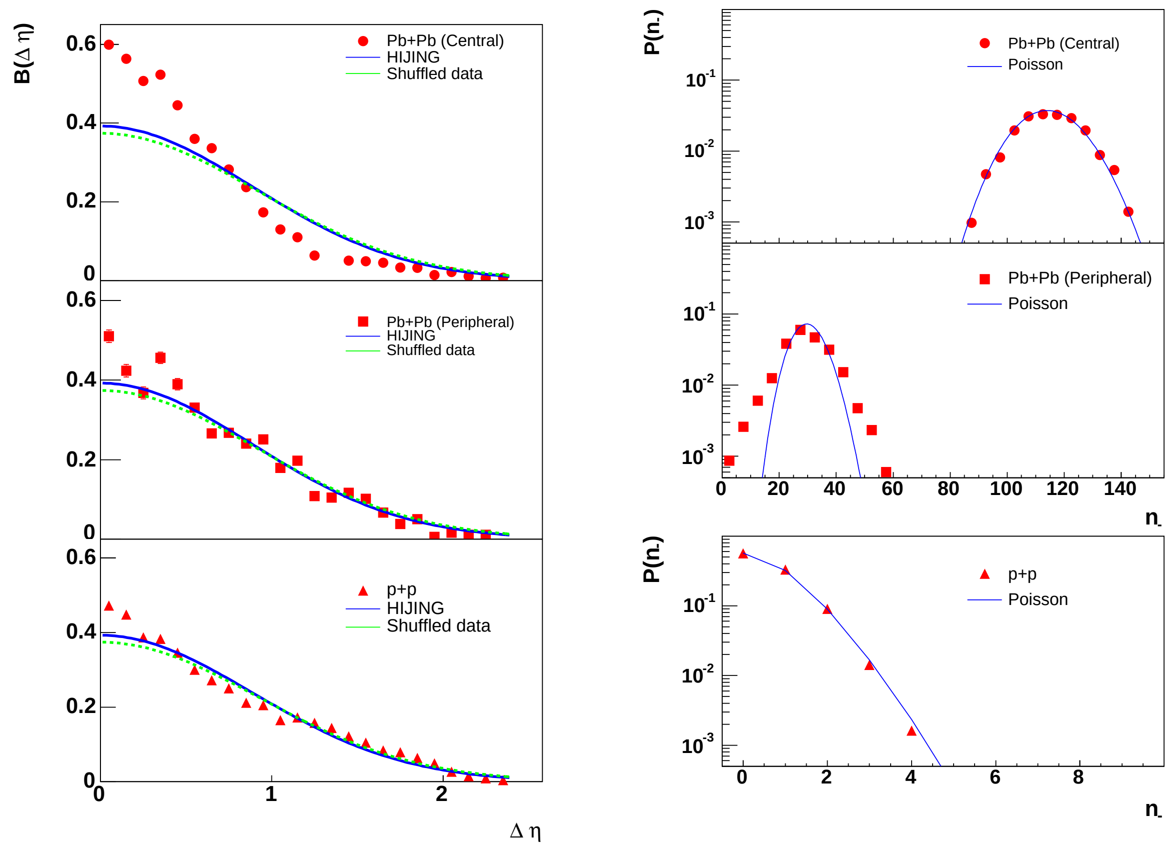

FIG. 5. Left: The dependence of the balance function, $B(\Delta\eta)$, on pseudo-rapidity interval, $\Delta\eta$, for selected reactions at 158 AGeV. Right: The multiplicity distributions of negatively charged particles, $P(n_-)$ for selected reactions at 158 AGeV.

The width of the balance function in pseudo-rapidity calculated as

$$\langle \Delta\eta \rangle = \int_{0.1}^{2.4} \Delta\eta B(\Delta\eta) d\Delta\eta / \int_{0.1}^{2.4} B(\Delta\eta) d\Delta\eta \tag{2}$$

is plotted in Fig. 6 as a function of $\langle N_W \rangle$ for all studied reactions at 158 AGeV. A monotonic decrease of $\langle \Delta\eta \rangle$ with increasing $\langle N_W \rangle$ is observed. The width of the balance function obtained for Hijing and "shuffled" events is approximately independent of $\langle N_W \rangle$, see Fig. 6. The reduction of $\langle \Delta\eta \rangle$ expressed by the ratio $(\langle \Delta\eta \rangle(data) - \langle \Delta\eta \rangle(shuffled))/\langle \Delta\eta \rangle(shuffled))$ amounts to about 30% for central Pb+Pb collisions at 158 AGeV. A similar reduction was measured in central Au+Au collisions at RHIC energies [16]. Originally a narrowing of the balance function was predicted as a signal of late hadronization [14]. Recently the observed effect at RHIC energies is partly explained within the models which assume a transverse flow of freezing-out matter and either quark coalescence [17] or decay of resonances [18].

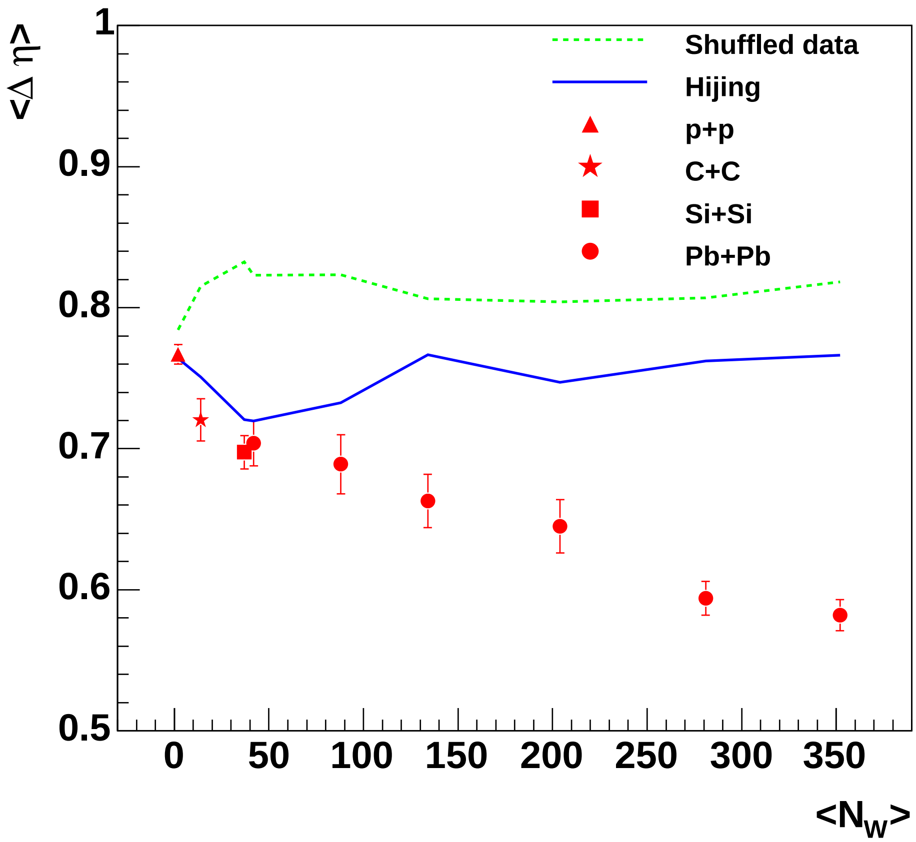

FIG. 6. The dependence of the width of the balance function, $\langle \Delta\eta \rangle$, on the mean number of wounded nucleons, $\langle N_W \rangle$, for various reactions measured at 158 AGeV. The experimental data are compared with the corresponding results for Hijing and "shuffled" events.

The multiplicity distributions of negatively charged hadrons produced in p+p interactions as well as peripheral and central Pb+Pb collisions at 158 AGeV are shown in Fig. 5 (right). Only hadrons in the forward hemisphere ($1.1 < y < 2.6$) which passed the NA49 acceptance filter [22] were used for the analysis. About 15% of all negatively charged hadrons are accepted. For Pb+Pb collisions the fluctuations in the number of projectile spectators, and thus in the number of projectile participants, were reduced by selecting narrow bins in the forward energy measured by the NA49 Veto calorimeter [1]. The distribution for p+p interactions and central Pb+Pb collisions are similar to a Poisson distribution (solid lines in Fig. 5 (right)). For peripheral Pb+Pb collisions the measured distribution is significantly broader than Poisson.

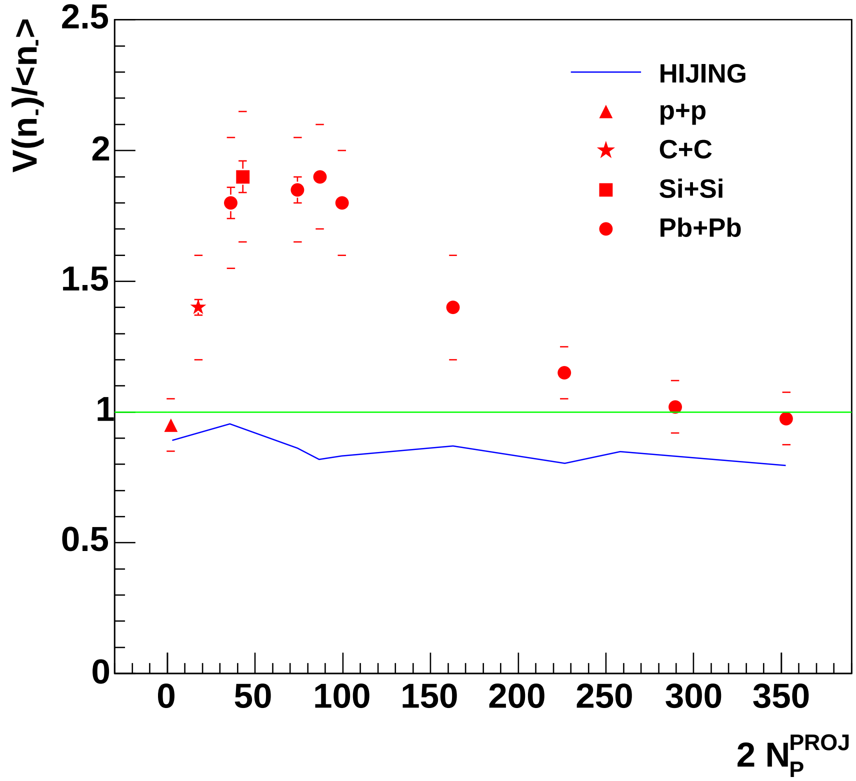

FIG. 7. The dependence of the ratio of variance to mean for the multiplicity distributions of negatively charged hadrons on the number of projectile participants, N_P^{PROJ}, measured in various reactions at 158 AGeV. Results obtained within the string-hadronic model Hijing are shown by the solid line.

The ratio of the variance ($V(n_-) = \langle n_-^2 \rangle - \langle n_- \rangle^2$) to the mean ($\langle n_- \rangle$) of the multiplicity distributions of negatively charged particles is plotted in Fig. 7 as a function of the number of projectile participants, N_P^{PROJ}. The ratio was corrected for the fluctuations in N_P^{PROJ} because of the finite width of the bins in the energy measured by the Veto calorimeter and its resolution [20]. The dependence of the ratio $V(n_-)/\langle n_- \rangle$ on N_P^{PROJ} exhibits a maximum at about $2N_P^{PROJ} \approx N_W \approx 70$. Note, that the transverse momentum fluctuations expressed by the Φ_{p_T} measure show a similar behaviour [21,22]. The observed large fluctuations for the intermediate mass systems were not predicted. Their origin is unclear.

4. Summary and the new programme at the CERN SPS

The energy dependence of hadron production in central Pb+Pb collisions shows anomalies which are consistent with the hypothesis that the onset of the deconfinement phase transition is located at about 30 AGeV. Selected results which illustrate this conclusion are plotted in Fig. 8 (left) using a common energy scale.

Large multiplicity and transverse momentum fluctuations are measured for intermediate mass systems ($N_W \approx 70$) at 158 AGeV. The corresponding results are summarized in Fig. 8 (right) using a common system size scale. For comparison the system size dependence of the $\langle K^+ \rangle / \langle \pi^+ \rangle$ ratio measured by NA49 in the same reactions is also plotted. The origin of the observed large fluctuations is unclear.

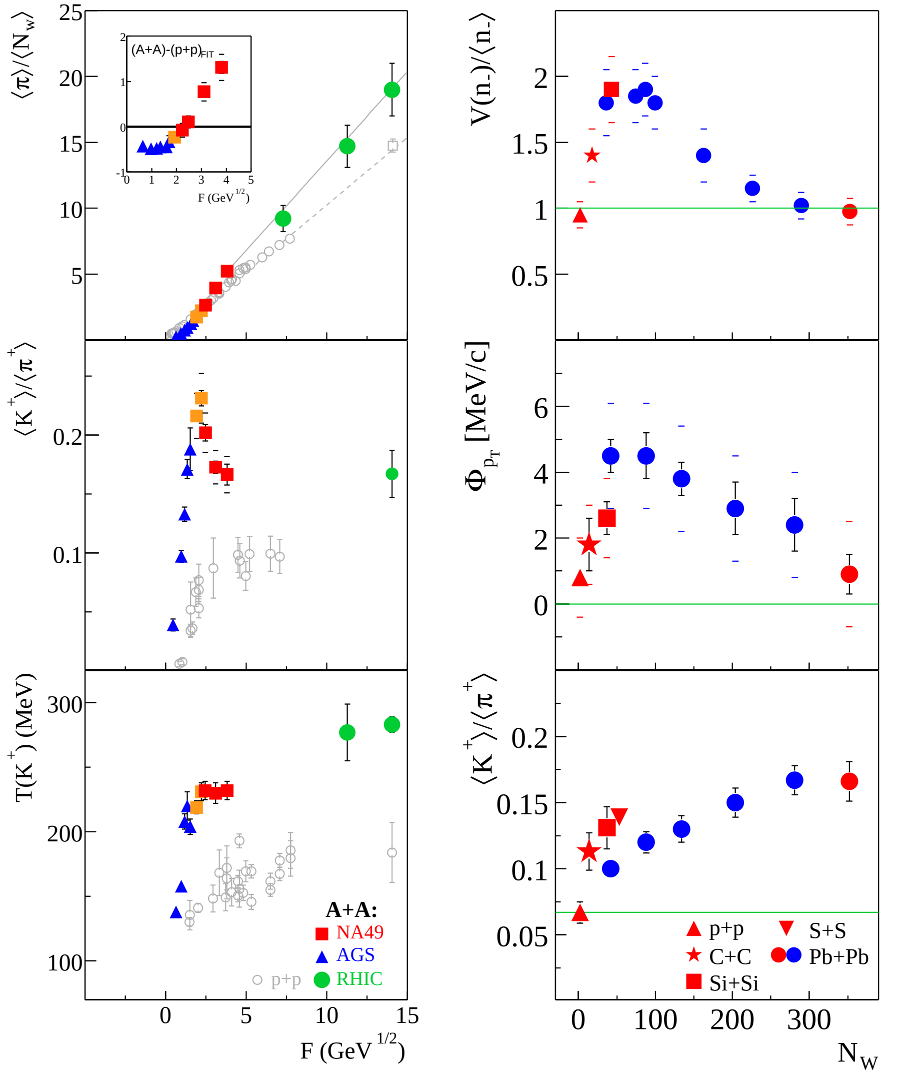

FIG. 8. Left: The energy dependence of selected hadron production properties measured in central Pb+Pb (Au+Au) collisions (solid symbols) and p+p interactions (open symbols). The changes in the SPS energy range (solid squares) suggest the onset of the deconfinement phase transition. Right: The system size dependence of the selected hadron production properties at 158 AGeV. Rapid changes are observed for small and intermediate mass systems. In particular fluctuations in multiplicity and transverse momentum reach a maximum at about $N_W \approx 70$.

A schematic graphical summary of the experimental situation is shown in Fig. 9. It is obvious that the turn on of the horn-kink-step like structures is located in collisions of light or intermediate mass nuclei at the low SPS energies. It is not clear at all how the observed large fluctuations at 158 AGeV will evolve with energy. Do they disappear at low energies, below the onset of deconfinement in heavy ion collisions? What are the fluctuations in the transition energy range?

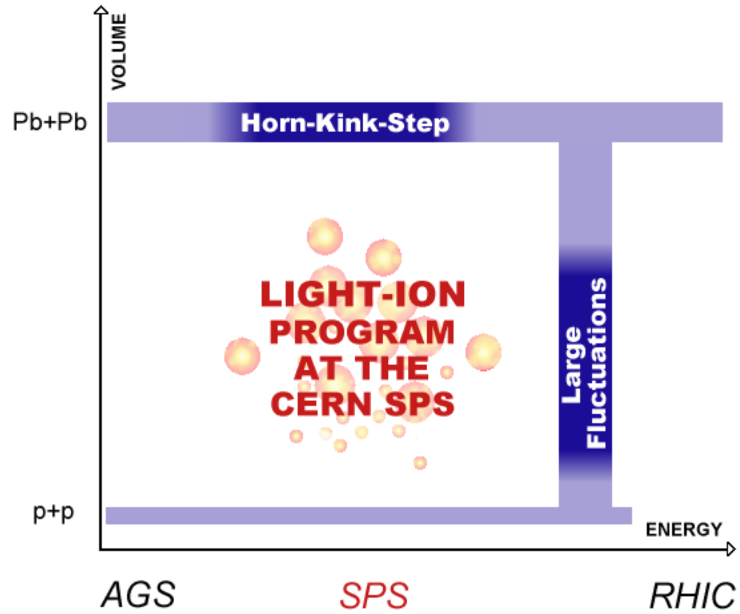

FIG. 9. A schematic summary of the recent results at the CERN SPS. The domain of necessary future studies is indicated.

New measurements are needed in the SPS energy range in order to answer these and other questions with the final goal to understand the role played by the volume of strongly interacting matter in determining the onset of the deconfinement phase transition. Recently an Expression of Interest [23] for performing these, but also other necessary measurements was submitted to the CERN SPS Committee. This new exciting experimental study could start in three years from now.

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